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# Residual Deep Plowing Effects on Irrigation Intake for Pullman Clay Loam

R. R. Allen,* J. T. Musick, and A. D. Schneider

## ABSTRACT

**Pullman clay loam (fine, mixed, thermic Torrertic Paleustoll) and related soils predominate in the southern High Plains of the USA. They are slowly permeable but respond to deep tillage with increased irrigation water intake. A one-time deep moldboard plowing to 0.4-, 0.6-, or 0.8-m depths was performed in 1966 to evaluate the inversion and mixing of the slowly permeable Bt1 horizon with the Ap horizon. We hypothesized that these deep tillage effects would still be present after 25 yr. We report irrigation intake effects with 5 yr (four growing seasons) of cropping to winter wheat (*Triticum aestivum* L.) beginning in 1988. After moldboard plowing to 0.2 m to restore surface tillage layer permeability, residual effects from the 1966 deep plowing caused an average increase in intake of 26% (129–163 mm) for the 0.4-m plow depth, compared with the 0.2-m check, for the first irrigation after tillage from 1988 to 1992. Irrigation intake increased 40% (52 mm) with 0.6-m deep plowing; however, there was no additional increase for 0.8-m plowing. Grain yields increased from 4.2 to 5.0 Mg ha$^{-1}$ (19%) for the 0.4-m or deeper plowing. The 1966 deep tillage also increased deep soil water storage between the 1- and 2.3-m depths during 1988 to 1992. Water use efficiencies were ≈8% greater for the deep plowing treatments.**

About 40% of the 2 million hectares of irrigated soils in the southern High Plains are slowly permeable clays and clay loams (Musick et al., 1988). Pullman clay loam and closely related soils predominate (Unger and Pringle, 1981). About 60% of these soils are irrigated through graded furrows. Water intake during furrow irrigation can be relatively high (150–200 mm) for the first application after primary tillage. Intake during the irrigation season declines to 75 to 100 mm after furrow consolidation. Irrigations are typically applied in 12- to 24-h sets on 400- to 800-m furrow lengths, and the soil is wetted from 0.6 to 0.9 m deep. Most field crops extract available soil water from 1.5 to 1.8 m in depth.

In the southern High Plains, declining groundwater levels reduce irrigation well output and the area that a producer can irrigate. To limit irrigation demand during the major water use periods, deep profile soil water storage is useful to meet transpiration demands and to reduce adverse water deficit effects on yield. The Pullman profile can store ≈250 mm of available soil water for extraction by winter wheat to the 1.8-m depth. Starting the season with a wet soil profile is very important for obtaining relatively high wheat yields with limited irrigation water supplies. This effect is illustrated for winter wheat by Musick et al. (1994). Deep tillage of slowly permeable clays can increase deeper soil profile wetting, and can be particularly effective for maintaining yields on the lower sections of graded furrow fields where intake opportunity time is less.

Hauser and Taylor (1964) reported that disk plowing Pullman soil to the 0.6-m depth in 1958 increased water intake during the first 10 h by ≈1.9 times, averaging 64 mm with deep plowing. In this case, all treatments received the same water application depth by flooding level bordered plots, and grain sorghum [*Sorghum bicolor* (L.) Moench] yields were only affected by the deep plowing in one of three years. Eck (1986) reviewed the effects of vertically mixing the Pullman soil profile (PM) to 0.9- and 1.5-m depths using a trenching machine. Alfalfa (*Medicago sativa* L.) and grain sorghum responded with increased production and WUE, especially with deficit irrigation on PM treatments. Wheat production response to PM was small and did not justify costs. Unger (1993) reported that irrigation infiltration and wheat plant rooting were still increased by the PM treatments after 25 yr, although wheat yields were not significantly increased.

The deep tillage treatments reported in this study were performed as a one-time deep moldboard plowing in 1966 to 0.4, 0.6, and 0.8 m on Pullman clay loam at Bushland, TX. Initial results from the tillage and irrigation tests were reported by Schneider and Mathers (1970), Mathers et al. (1971), and Musick and Dusek (1975). Musick et al. (1981) reported results after 13 yr. We report long-term residual effects (25 yr) on irrigation water intake after deep tillage on a slowly permeable clay soil. Deep tillage effects on irrigation water intake, soil water use, and crop production were compared with a conventional tillage check where tillage depth did not exceed 0.2 m.

## MATERIALS AND METHODS

The Pullman soil profile at the study site (102° W, 33.5° N) has a dark brown clay loam Ap horizon and has been described by Unger and Pringle (1981). It has a medium granular structure to about the 0.15-m depth, which is also the zone penetrated by most tillage operations. The Bt1 horizon is a dense dark brown clay with a medium blocky structure, which extends from 0.15 to 0.4 m in depth. It is underlain by a reddish brown clay Bt2 horizon to a depth of 0.75 m. The Bt horizons have bulk densities of 1.5 to 1.6 Mg m$^{-3}$. The clay fraction is dominated by montmorillonite. For the Ap soil horizon, particle-size distribution averaged 17% sand, 53% silt, and 30% clay. Organic matter was 20.1 g kg$^{-1}$ and pH was 7.43. When dry, the soil develops shrinkage cracks that result in a relatively high initial water intake rate. After initial filling of cracks or saturation of a loosened surface tillage layer, intake rates decline to the basic rate after 2 to 3 h of graded furrow irrigation.

The plot area was 4 ha. To accommodate the large plow and trac-tractors (Fig. 1), main plots (plow depth) were 12.2 m wide and the entire field length (300 m). The plow, capable of depths to 1.3 m, can be used to invert and mix deeper soil layers with shallower horizons. The plow description and procedure used was described by Schneider and Mathers

USDA-ARS, Conservation and Production Research Lab., P.O. Drawer 10, Bushland, TX 79012. Contribution from the USDA-ARS, Conservation and Production Research Lab., Bushland, TX 79012. Received 6 Oct. 1994. *Corresponding author.

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**Abbreviations:** PM, profile modification; WUE, water use efficiency; ET, evapotranspiration; HC, hydraulic conductivity.

See end of document for photograph that appeared as Fig. 1

**Fig. 1. Deep moldboard plowing, April 1966.**

(1970). There were two main plow depth plots for each treatment, each with two 6.1 by 300 m subplots to provide four replications.

This study was conducted during 1988 to 1992 by cropping to winter wheat. Cropping from 1966 to 1987 included irrigated grain sorghum, sugarbeet (*Beta vulgaris* L.), corn (*Zea mays* L.), and wheat. Tillage depth did not exceed 0.2 m at any time between 1966 and 1987. Plots were moldboard plowed to the 0.2-m check treatment depth near 1 Sept. in 1988, 1990, and 1991. In 1989, tillage was by multiple disking in early September because the soil was too wet for timely moldboard plowing. In each year, 1.0-m-spaced bed furrows (300 m long) were formed after disking and applying fertilizer at 145 kg $ha^{-1}$ N in the form of anhydrous $NH_3$. Furrow grade was 0.75%. Seeding of TAM 200 wheat cultivar was done using a double-disk opener grain drill in 20-cm-spaced rows providing three rows per bed and two rows per furrow. Seeding rates were 0.067 Mg $ha^{-1}$.

Irrigation was applied through gated pipe and measured with a propeller meter with flow to individual furrows adjusted volumetrically to 0.63 L $s^{-1}$. The relatively low furrow stream size was selected because of the grade, low permeability, and a relatively short furrow length. Runoff measurements were made from four furrows per plot with individually calibrated H-flumes equipped with FW-1 water stage recorders. Two of the four furrows for runoff measurement had wheel traffic. A commercially available personal computer interface digitizing tablet was used to determine water stage heights on flume runoff hydrographs, from which flow volumes were calculated. Runoff was allowed for 4 to 6 h.

Soil water contents were measured gravimetrically by 0.3-m increments to the 1.8-m depth at the beginning and end of the season and before and after selected irrigations. Volumetric soil water content conversions were based on bulk densities determined with soil cores obtained in 70-mm increments and averaged for each 300-mm soil depth. Seasonal water use was determined by the water balance method using beginning and end-of-season soil profile water contents, net applied irrigation, and precipitation. Wheat yields were determined by harvesting three 1.4 by 15 m sample areas per plot with a plot combine. Grain yields were adjusted to 130 g $kg^{-1}$ moisture, wet basis. Water use efficiency was determined as the ratio of grain yield to seasonal ET (water use including net irrigation). Subplot treatment means were tested for statistical significance at the $P < 0.05$ level using Statgraphics[1] (Manugistics, 1992) for analysis of variance.

[1] The mention of trade or manufacturer names is made for information only and does not imply an endorsement, recommendation, or exclusion by the USDA-ARS.

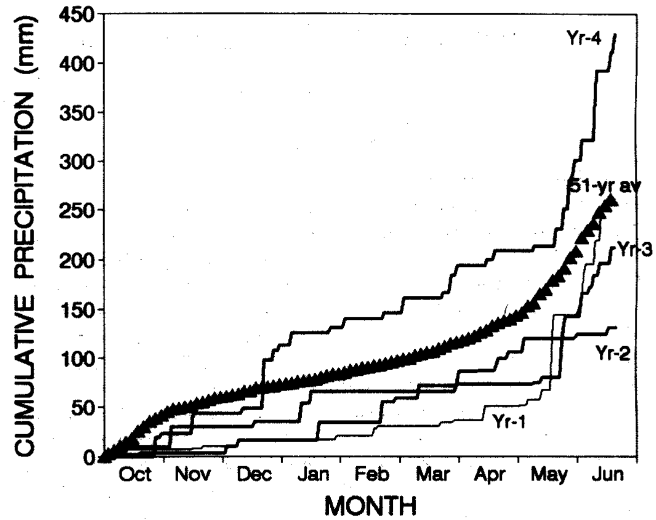


**Fig. 2. Cumulative precipitation during 1988 to 1992 winter wheat growing seasons compared with 51-yr average, Bushland, TX (Years 1, 2, 3, and 4 = growing seasons 1988–1989, 1989–1990, 1990–1991, and 1991–1992, respectively).**

Irrigation water intake was also measured using a flowing furrow infiltrometer (Dedrick et al., 1985) after moldboard plowing to 0.2 m, disking, bedding, and planting in the fall of 1990. The flowing furrow infiltrometer permitted measuring intake rate and cumulative intake effects under more controlled conditions and partitioning the effects of furrow wheel traffic. Infiltrometer measurements were made in blocked 4.5-m-long sections of furrow. Four replicated tests of 8-h duration were conducted. Because of limited time for conducting infiltrometer tests, both wheel track and nontrack furrows were tested for the 0.2- and 0.4-m plow depths, while only nontrack furrows were tested for the 0.6-m plow depth.

# RESULTS

For discussion, the four crop seasons 1988–1989, 1989–1990, 1990–1991, and 1991–1992 will be referred to as Years 1, 2, 3, or 4, respectively.

## Seasonal Precipitation

The cumulative growing season precipitation for the four complete crop seasons is presented with the long-time average for comparison in Fig. 2. This graph illustrates that both the distribution and the quantity of precipitation in the southern Great Plains can vary widely during a 4-yr period. In Year 1, precipitation was considerably below average until near the end of the crop season in late May when the crop was destroyed by hail. Years 2 and 3 were below average in precipitation, and Year 4 was ≈70% above average.

## Irrigation Water Intake

Dates of irrigation applications are presented in Table 1, and irrigation intake for each application is presented in Table 2. The term *plow depth* refers to the depth of moldboard plowing of the original deep plowing treat-

Table 1. Moldboard plow, planting, irrigation, and harvest dates, Bushland, TX.

| Year | 0.2-m plow | Plant date | Irrigation dates | | Harvest |
|---|---|---|---|---|---|
| | | | Preseason | Seasonal | |
| 1988-1989 | 6 Sept. | 4 Oct. | 14 Sept. preplant† | 14 Mar., 1 May | Hail‡ |
| 1989-1990 | § | 26 Sept. | 7 Nov. postplant | 7 May, 22 May | 21 June |
| 1990-1991 | 15 Sept. | 27 Sept. | 18 Oct. postplant | 9 April, 14 May | 25 June |
| 1991-1992 | 1 Sept. | 1 Oct. | 19 Sept. preplant | 25 Mar., 28 April | 28 June |

† Prepl. = irrigation before planting. Postpl. = irrigation after planting.
‡ No harvest because of hail.
§ Moldboard plowing was not performed because of wet soil.

ments in 1966. In each year of this study, the residual effect from deep loosening and mixing of the A and Bt1 soil horizons in 1966 resulted in increased water intake with depth of tillage through 0.6 m, especially for the preseason irrigation after primary tillage in early fall (Table 2). The residual deep plowing effect on intake was limited to 0.6 m, as evidenced by plowing to 0.8 m having no additional residual effect in any year (Table 2). For the spring (seasonal) irrigations, the effects of deep plowing were reduced substantially because of surface soil consolidation but the effects were still evident (Table 2). In Year 2 when fall tillage was limited to disking to only 0.12 m in depth, the effect of initial plow depth on intake was less than in other years when plots were fall moldboard plowed to 0.2 m (Table 2). Preseason irrigation intake for the 0.4-m plow depth treatment averaged 163 mm, 27% higher than the 0.2-m check at 129 mm (Table 2).

Soil water content with depth before and after the preplant irrigation on 14 Sept. 1988 is presented in Fig. 3. Soil water values before the preplant irrigation are averaged because differences between treatments were negligible. A 125-mm rain occurred immediately after the irrigation and before soil sampling could be done, so the depth of gravimetric sampling was extended to 3 m to determine the extent of deep profile wetting from the irrigation and rainfall following irrigation. On the deep plowing treatments that extended to 0.4 m or more in depth, deep profile soil water storage occurred within the 1- to 2.3-m depth. The sharp increase in soil water content with depth from ≈1.3 to 1.7 m (Fig. 3) is associated with the beginning of a caliche layer containing varying amounts of $CaCO_3$. The $CaCO_3$ contents at the top of the caliche layer reach ≈50% then decline to ≈15% deeper in the profile. Very little soil wetting was evident below the 2.3-m depth.

Irrigation water intake during the first application after moldboard plowing to 0.2 m in 1990 and 1991 (comparable years in terms of precipitation) is presented in Fig. 4 for comparison with results of Musick et al. (1981) following moldboard plowing to the 0.2-m depth in 1975 and 1978, and for comparison with the average of 66 irrigations between 1966 and 1979 that largely represent present conditions of surface-layer soil consolidation. Intake amounts 25 yr after deep plowing were similar to those after 9 to 12 yr. The difference was slightly less for the 0.6- and 0.8-m plow depths in 1990. Intake after 25 yr remained 30 to 40% higher than when only surface tillage was done from 1966 to 1979.

## Infiltrometer Tests and Hydraulic Conductivity

Infiltration rates and 8-h cumulative infiltration as measured by a flowing furrow infiltrometer are presented in

Table 2. Treatment effects on irrigation water intake, evapotranspiration (ET), yield, and water use efficiency (WUE), Bushland, TX.

| Crop year | 1966 till depth | Irrigation intake: Preseason | Seasonal 1st | Seasonal 2nd | Total | Season precipitation | ET | Grain yield | WUE |
|---|---|---|---|---|---|---|---|---|---|
| | m | mm | | | | | | Mg ha$^{-1}$ | kg m$^{-3}$ |
| 1988-1989 | 0.2 | 124b† | 112b | 76b | 312c | –‡ | – | –‡ | – |
| | 0.4 | 138b | 137a | 87ab | 362b | – | – | – | – |
| | 0.6 | 170a | 142a | 88ab | 400ab | – | – | – | – |
| | 0.8 | 173a | 150a | 95a | 418a | – | – | – | – |
| 1989-1990 | 0.2 | 126b | 80b | 61a | 267b | 132 | 556a | 3.65b | 0.65a |
| | 0.4 | 145ab | 83ab | 65a | 293ab | | 586a | 4.02ab | 0.69a |
| | 0.6 | 147ab | 94ab | 67a | 308a | | 596a | 4.32a | 0.72a |
| | 0.8 | 154a | 96a | 71a | 321a | | 605a | 4.35a | 0.72a |
| 1990-1991 | 0.2 | 135b | 147b | 116b | 398c | 207 | 621c | 4.33b | 0.70b |
| | 0.4 | 171a | 154ab | 128ab | 453b | | 696b | 5.56a | 0.80a |
| | 0.6 | 184a | 159ab | 141a | 484ab | | 762a | 5.71a | 0.75ab |
| | 0.8 | 188a | 175a | 146a | 509a | | 787a | 5.64a | 0.72b |
| 1991-1992 | 0.2 | 127c | 112a | 97a | 336c | 448 | 627a | 4.73b | 0.75b |
| | 0.4 | 172b | 115a | 97a | 384b | | 643a | 5.37a | 0.83a |
| | 0.6 | 212a | 121a | 101a | 434a | | 649a | 5.28a | 0.81ab |
| | 0.8 | 221a | 126a | 108a | 455a | | 664a | 5.37a | 0.81ab |

† Variables followed by the same letter in individual years are not significantly different at the 0.05 level of probability according to Duncan's multiple range test.
‡ 1989 crop destroyed by hail, and soil water related data are not reported.

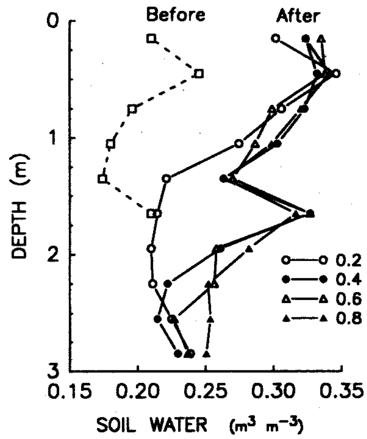


**Fig. 3. Residual deep tillage effect on soil water contents with depth before and after preplant irrigation on 9 Sept. 1988 and a 125-mm rain after irrigation. Soil water values before the preplant irrigation are averages of all treatments.**

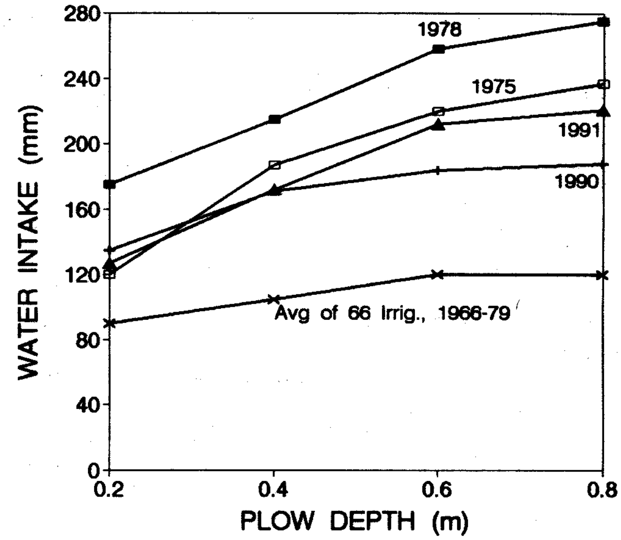


**Fig. 4. Preseason irrigation intake effects for loosened surface-layer condition following moldboard plowing to 0.2 m in 1990 and 1991, compared with the data of Musick et al. (1981) and the long-term averages from all investigations, which mostly represent consolidated surface-layer soil conditions.**

Fig. 5a and 5b, respectively, for 0.2-, 0.4-, and 0.6-m plow depths. The effect of furrow wheel traffic on infiltration is presented for the 0.2- and 0.4-m plow depths. Infiltration rates were relatively high, ranging from 100 to 180 mm $h^{-1}$, until soil shrinkage cracks were filled. Then infiltration rates were reduced to the 20 to 45 mm $h^{-1}$ range after $\approx 1$ h.

Traffic effects on infiltration were more apparent from the 8-h cumulative infiltration curves than from the infiltration rate curves (Fig. 5). Infiltration from both 0.2- and 0.4-m plow depths with wheel traffic were very similar (Fig. 5b), indicating that surface-layer compaction in the furrow controlled intake. Traffic significantly reduced 8-h infiltration by $\approx 23\%$ on the 0.2-m check and $\approx 43\%$ on the 0.4-m plow depth. Compaction by wheel traffic in furrows increases bulk density with the effect extending to $\approx 150$ mm below the furrow on this soil as reported by Allen and Schneider (1992). With the use of nontraffic furrows on the 0.2-m plow depth (check) as a basis for comparison, the 0.4- and 0.6-m plow depths significantly increased infiltration by 66 and 86 mm or 41 and 54%, respectively. Infiltration for the 0.6-m plow depth was not significantly greater than for the 0.4-m plow depth.

Aronovici et al. (1969) measured HC through undisturbed cores on Pullman clay loam at Bushland and found two zones of very restricted permeability in the B horizon. These occurred at the 0.2- to 0.4- and 1.1- to 1.3-m depths (Fig. 6) where HC values declined to $\approx 1.0$ mm $h^{-1}$. The relatively sharp increase in HC near the 1.5-m depth occurs at the top of the caliche layer, which has visual indications of high macroporosity.

## Soil Water Depletion, Evapotranspiration, Grain Yield, and Water Use Efficiency

The depletion of soil water from the preseason irrigation on 10 Oct. 1990 to harvest in June 1991 is presented in Fig. 7 for Year 3 when growing season precipitation was 207 mm and nearest to the long-term average. After-harvest soil water values are averaged because of negligible differences between treatments. The wheat crop extracted soil water to $\approx 1.5$ m in depth. Soil water storage below the 1.0-m depth for the 0.6- and 0.8-m plow depth treatments was slightly higher than for the 0.4-m depth.

Seasonal ET, grain yield, and WUE are presented in Table 2. Because of increased total irrigation intake and profile depletion with increasing plow depth, ET was also increased with plow depth. Both grain yield and WUE were significantly increased by increasing plow depth from 0.2 to 0.4 m in Years 3 and 4; however, deeper plowing to 0.6 and 0.8 m had only a minor effect on grain yield and WUE. Our average seasonal ET, 600 to 670 mm, was slightly lower than the average 733 mm reported by Musick et al. (1994) for 6.1 Mg $ha^{-1}$ yields obtained from adequate irrigation treatments in 14 yr of field irrigation studies conducted on nearby sites.

Grain yields of 3.6 to 4.3 Mg $ha^{-1}$ in Year 2 were $\approx 20\%$ below those for Years 3 and 4. The yield reduction in Year 2 was caused by relatively low fall tillering plus high temperatures and ET during late-season grain filling. In Year 2, the ET demand for wheat at Bushland, as measured with weighing lysimeters (Steiner et al., 1991), was $\approx 260$ mm between the final irrigation on 23 May and physiological maturity on 22 June of 1990. This ET exceeded available soil water after the irrigation by $\approx 40$ mm.

## DISCUSSION

It is apparent that periodic loosening to the 0.2-m soil depth restores much of the higher intake achieved 25 yr earlier by the inversion-mixing action of moldboard plowing into the dense Bt subsoil. The implications are that one-time deep mixing of soils with slowly permeable layers can provide continued benefit in irrigation water intake for many years with proper surface-layer soil

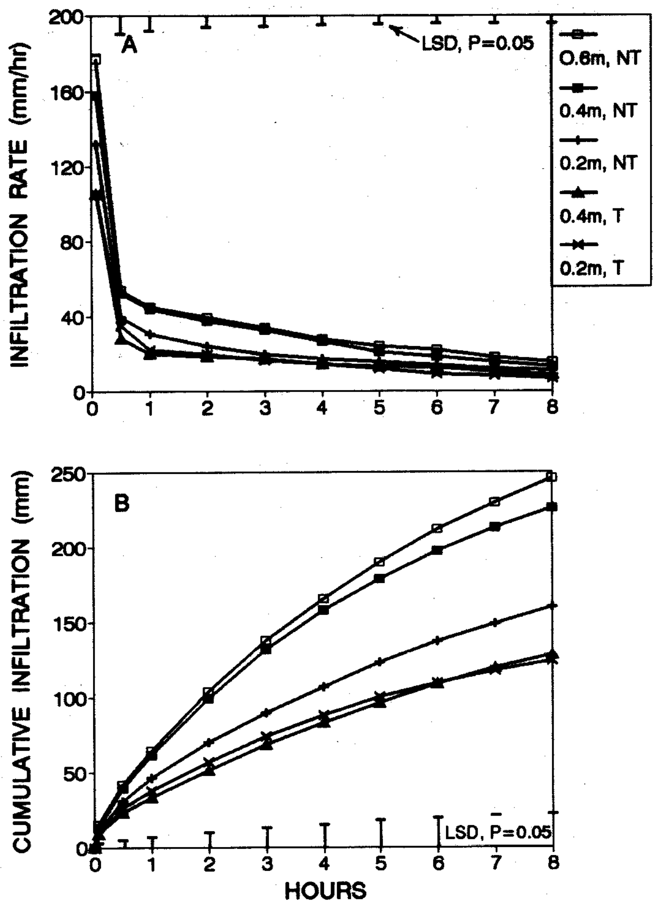


**Fig. 5. Infiltration measured by flowing furrow infiltrometer during 8-h tests for three moldboard plowing treatment depths including comparative traffic (T) and no-traffic (NT) furrows, presented as (A) infiltration rates and (B) cumulative infiltration (LSD = least significant difference).**

management! The improved permeability increases the depth and amount of soil water storage and the improved physical condition increases rooting depth to take advantage of deeper soil water storage as reflected by increased

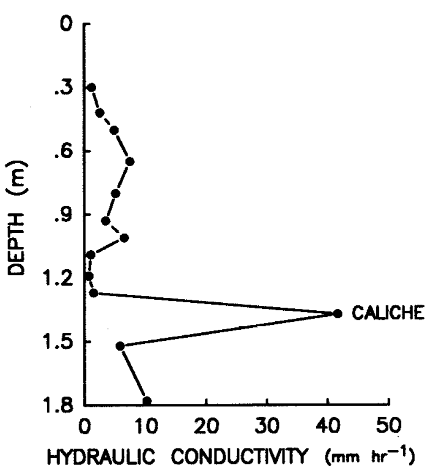


**Fig. 6. Hydraulic conductivity with depth of Pullman clay loam through undisturbed cores (Aronovici et al., 1969).**

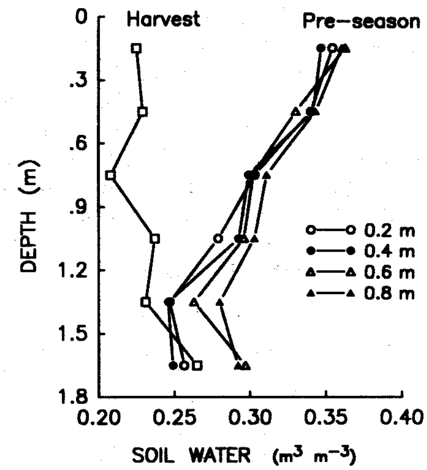


**Fig. 7. Depletion of soil water with depth for deep plowing treatments following a preseason irrigation on 18 Oct. 1990 until harvest on 25 June 1991. Harvest soil water values are averages of all treatments.**

extraction with depth. The result is a significant increase in grain yield where one-time moldboard plowing to 0.4 m is performed. This yield increase also can result in higher WUE.

Beginning a winter wheat crop season with a wet profile is a desirable management practice. The deep profile reserve can reduce irrigation requirements in the spring when there is conflict with demands for preplant-emergence irrigations of summer row crops.

Since 400- to 800-m row lengths are common for graded furrows, the intake opportunity time on the upper two-thirds to three-fourths of fields is usually adequate to rewet the soil to about the 0.9-m depth without the soil profile mixing effect of deep tillage. Thus, deep tilling the upper portions of fields is usually not necessary. A practice with some graded furrow irrigators on slowly permeable clays has been to moldboard plow to about the 0.3-m depth every third year. A more effective management practice would be to perform deep plowing to about a 0.4-m depth on about the lower one-fourth of a field and maintain this lower field section by annual plowing to 0.2 m to remove the effects of traffic compaction. The increased intake rates can compensate for reduced lower field section opportunity time. This practice can limit the duration and amount of tailwater runoff. The cost to plow 0.4 m deep with a producer-owned tractor and reversible moldboard plow is estimated to be \$50 to \$60 $ha^{-1}$.

To maintain the surface-layer soil physical condition, the common producer practice of shallow disking to $\approx$0.12 m is not as effective as moldboard plowing to 0.2 m, as Musick et al (1981) reported in earlier tests. The cumulative infiltration curves in Fig. 5b (from infiltrometer tests) illustrate the major effect of both deeper than normal tillage on intake during the first irrigation after primary tillage. The impact of furrow wheel traffic on irrigation advance and intake is less in producer's fields where wider equipment is used. Two wheel tracks per pass of 8- or 12-row equipment only compacts 17 to 25% of furrows, compared with 50% of the furrows being compacted on these research plots.

Producers have the opportunity to use readily available agricultural tillers and power units to invert or loosen dense subsoil below normal tillage depth, rather than leasing or purchasing relatively heavy equipment for a one-time operation. These tillers include reversible moldboard plows, bent-leg tillers, and subsoilers that can operate from 0.35 to 0.4 m in depth.

## CONCLUSIONS

The very long-term residual effect from vertically mixing the A and B soil horizons increased irrigation water infiltration after primary tillage. Soil surface consolidation during successive seasonal irrigations, precipitation events, and cultural operations reduced the effect later in the season. The effect can readily be restored by moldboard plowing the Ap soil horizon $\approx 0.2$ m deep. Without annual loosening of the Ap horizon, soil surface conditions, rather than subsoil permeability, largely control intake rates.

After 25 yr, the soil mixing effect of moldboard plowing deeper than 0.2 m into the blocky-structured Bt1 soil horizon still affected irrigation intake by increasing infiltration an average of 26 and 40% for 0.4- and 0.6-m initial deep plowing depths. The greatest and most significant incremental response was for the 0.4-m plow depth, which increased grain yield and WUE.

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Fig. 1. Deep moldboard plowing, April 1966.